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Modelling of solar radiation for West Africa: The Nigerian option

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The United Nations Framework Convention on Climate Change (UNFCCC) reports indicate that those who are least responsible for climate change are also the most vulnerable to its projected impacts. In no place is this more evident than in Sub Saharan Africa, where greenhouse gas (GHG) emissions are negligible from a global scale. In Africa, energy demands could be the major factor that may lead to the increase of its emissions in the very near future. Forests are being used up for domestic energy supply. Oil produced energy increases carbon foot prints and hydropower is unreliable due to uncertainties in rainfall patterns. By 2004, the energy consumption mix of West Africa was dominated by oil (58%), followed by natural gas (38%) and hydroelectric (8%) with coal and other energy forms not part of the mix. The Sayigh's universal equation is presented in this work, for estimating the global solar radiation analysing data from 1972 to 2004 in Nigeria using Umudike, as a case study. The global solar radiation within the region was noted to range from 1.99 to 6.75 kWh indicating that the method could be used in producing signatures of global solar radiation in Nigeria when actual measurements are not available.

Key words: Solar radiation, modelling, West Africa, Nigeria.

INTRODUCTION

Countries in West Africa face many of the same challenges as the rest of the world due to growing fuelling energy demand. Besides few exceptions such as Nigeria, the countries in the region do not have or have developed sufficient domestic resources so they have become dependent on imports. State companies which dominate the energy sector lack commercial incentives and tend to be inefficient; prices of fuels such as kerosene, diesel and electricity are heavily subsidized encouraging inefficient use of energy, deterring additional investment in energy supply and often resulting in shortages and rationing (Taimur et al., 2007).

Notwithstanding, combustion of these fuels for power supply unleashes intolerable amounts of carbon (iv) oxide as well as other harmful gases to the environment thus contributing in turning the earth's atmosphere to a greenhouse with the harmful effect of producing global warming. The environmental implications of gas emission from these sources including gas flaring are part of issues that informed the Copenhagen Climate Change Summit at Denmark in December 2009. The summit was aimed at creating global awareness of climate change as well as establishing treaties that can be supported by global businesses.

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This paper aims at recommending West Africa and Nigeria in particular to renewable energy, having estimated levels of global solar radiation at Umudike (latitude 5.29°N, longitude 7.33°E) Eastern Nigeria, using the Angstrom universal method from the period 1972 to 2004. Already, many countries like the United States of America, China, India and Brazil etc, are employing this initiative by the United Nations to start-up the clean development mechanism project, such as the use of solar power generation; biofuel generation from waste and investment in carbon trading amongst other things, geared at making the environment free from harmful emissions. With advancement in science and technology, the initiation to use solar energy for power generation is already in use towards meeting electricity needs. There are indications that the desire to diversify sources of electricity generation may become visible, following plans by the country's first solar electricity generation company to commence operation before the end of the year (Chineke, 2002; Igbal, 1983). The purpose of the work is to use different models for estimating global solar radiations in Nigeria for locations where no measured data is available.

MATERIALS AND METHODS

Study area

Nigeria is located in the tropics between 3°E to 14°E of longitude and 4°N to 14°N of latitude. She is endowed with an annual average daily sunshine of 6.25 h ranging between 3.5 h at the coastal areas and 9.0 h at the far northern boundary. The minimum and maximum hours of sunshine amount to 0.1 and 9.9 h respectively. Similarly, it has an annual average daily solar radiation of about 5.25 kWh/m^2 per day varying between 3.5 kWh/m^2 per day at the coastal areas and 7.0 kWh/m^2 per day at the Northern boundary. The minimum and maximum temperatures are 9.7 and 41.5°C respectively (Akinbami, 2001).

Acquisition of data

A monthly average temperature data obtained from the National Root Crop Research Institute (NRCRI) Umudike, for the period of 30 years ranging from 1972 to 2004 was used for this research work. The three models of estimating solar radiation is presented in this work but only the Sayigh's method was used to plot the signatures because of its accuracy, hence the three models were compared by combining all the models. In spite of the importance of global solar radiation data, few meteorological stations, especially in developing countries such as Nigeria measure these data accurately and continuously. The situation can be solved using equation methods that estimate global solar radiation from available meteorological parameters such as sunshine duration, daily temperature, relative humidity e.t.c (Akpabio and Etuk, 2003; Akpabio et al., 2005; Chineke, 2008). The correlation model developed can be used in estimating global solar radiation in locations of similar latitude, altitude and climatology. Empirical modelling is an essential and economical tool for the estimation of global solar radiation. There are several methods available for estimating global solar radiation (Chiemeka and Chineke, 2009; Chineke, 2008); however, for this work the following were considered.

Sayigh's equation

Sayigh proposed his universal formula for the estimation of total radiation intensity (Sayigh, 1977; El-Sahaam and Sayigh, 1979; Oduro-Afriyie, 1997), which relates the global solar radiation Rg, to mean maximum temperature Tmax, mean relative humidity RH, and the ratio of sunshine hours to the length of the day S1, expressed as:

$$Rg = NK \exp\{\varphi(S1 - RH/15 - 1/Tmax)\} \quad (1)$$

Where

$$N = 1.7 - 0.458\varphi \quad (2)$$

and

$$K = 1.163\ (a\ Z + bij\ Cos\ \varphi) \quad (3)$$

is a constant ($KWh/m^2/day$)

$$a = 0.2/(1 + 0.1\varphi - - - - - - \quad (4)$$

φ, the latitude in degrees; Z is the length of day in hours; the monthly average is taken in the middle of the month; K, N and a, are factors which can be computed using the equation above. bi j is a humidity factor, i=1,2,3 where 1 is for RH < 65%, 2 is for RH > 70%, and 3 is for 65% $\leq$ RH $\leq$ 70%. On the other hand, j = 1, 2, 3… 12 which refers to the months of the year.

Hargreave's equation

Chineke and Jagtap (1995) compared 3 models and got the best fit with the modified temperature based Hargreave's method (Hargreaves and Samani, 1982). The temperature-based model is most appropriate when data on sunshine hours is lacking like in the case for Nigeria. Chineke et al. (1999) proposed the equation for estimating solar radiation and presented it in the form:

$$Rs = 0.16RaTd_{1/2} \quad (5)$$

Where R_S = solar radiation, T_d = daily temperature difference (maximum minus minimum) values, Ra = extraterrestrial solar radiation (generated by a computer routine and requiring the locations grid parameter).

Angstrom equation:

This is one of the most popular models. It is a regression equation (Angstrom, 1924; 1929 and Black et al., 1954), which relates global solar radiation H, to the duration of sunshine S, being the parameter mostly readily measured at meteorological stations.
The model is thus expressed:

$$H + Ho = a + bs/Z \quad (6)$$

H = total horizontal solar radiation
Ho = extraterrestrial solar radiation

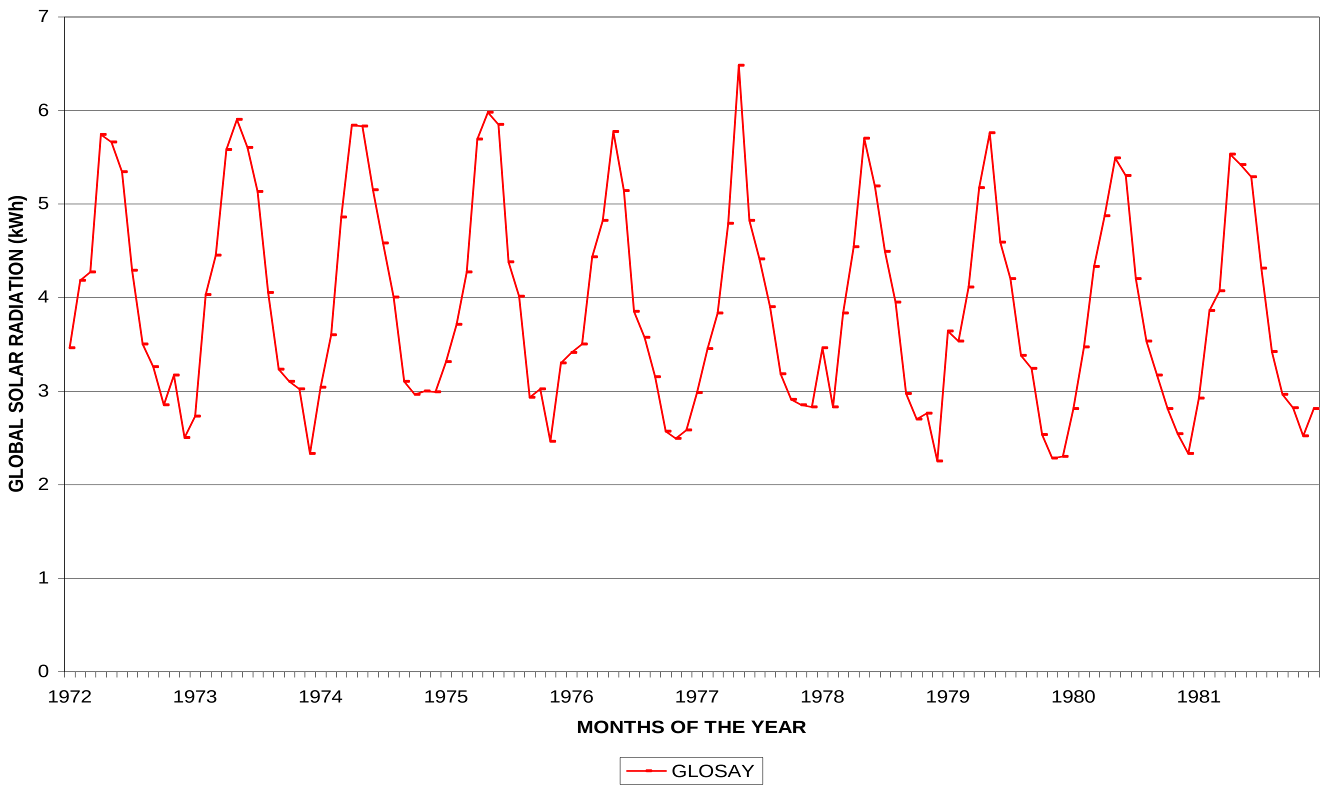

Figure 1. Global Solar Radiation for the first decade between 1972 to 1981.

S = Average sunshine hours per month
Z = length of the day in hours, the monthly average is taken in the middle of the month a and b are constants.

From the daily averages of the temperature and sunshine hour data, the global solar radiation was estimated for the region (Angstrom, 1924, 1929; Oduro-Afriyie, 1997; Chineke et al., 1999; Hargreaves and Samani, 1982; Taimur et al., 2007; Chineke, 2008; Chiemeka and Chineke, 2009). This would highlight how much the clearness index for the region could be established (Akpabio et al., 2005; Babatunde and Aro, 1995). For this analysis, the period of the study was grouped into four decades, ranging from 1972 to1981 for the first decade, 1982 to 1991 for the second decade, 1992 to 2001 for the third decade and the forth decade being the years from 2002 to 2004.

RESULT AND DISCUSSION

In Figures 1 to 3, the signatures of the estimates were shown creating a trend line for modelling and subsequently, the expected levels of solar radiation within the region. Within the first decade, the region recorded a maximum of 6.48 kWh in 1977 and a minimum of 2.25 kWh in 1978. However, the records of the estimated maximum levels of solar radiation that reached the region for the decade were 5.74 kWh in 1972; 5.9 kWh in 1973; 5.84 kWh in 1974; 5.98 kWh in 1975; 5.77 kWhin 1976; 5.7 kWh in 1978; 5.76 kWh in 1979; 5.49 kWh in 1980 and 5.53 kWh in 1981; as shown in Figure 1. From Figure 2, the trend line of the estimates of the second decade was similar to the first although with variation in the estimated maximum solar radiation, which was 6.23 kWh in 1988 and a minimum of 1.99 kWh in 1985. However, the records yet reflect the potentials of harnessing this source of renewable energy in areas of photovoltaic in rural electrification (Chineke, 2008; Chineke et al., 2007), evapotranspiration and agronomy (Okoro et al., 2008), to mention but a few.

The third decade ranging from 1992 to 2001 had its signature similar to those previously discussed. From Figure 3, the estimate showed the highest level in the maximum solar radiation within the period of study, which was 6.75 kWh in 1998, with similar high records of 6.06; 5.87; 6.05 and 5.98 kWh in the years 1995; 1996; 1997 and 2001 respectively. This could not be far from the truth as this period recorded the highest awareness on global warming and climate change. The gaps in the data were mainly due to unavailability of measurements of the variables for the months within the period.

Figure 4 showed that the levels of solar radiation were also high with maximums of 5.92, 6.09 and 6.1 kWh in the years 2002, 2003 and 2004 respectively; having minimums of 2.58, 2.38 and 2.5 kWh in the years 2002, 2003 and 2004 respectively. These earlier figures

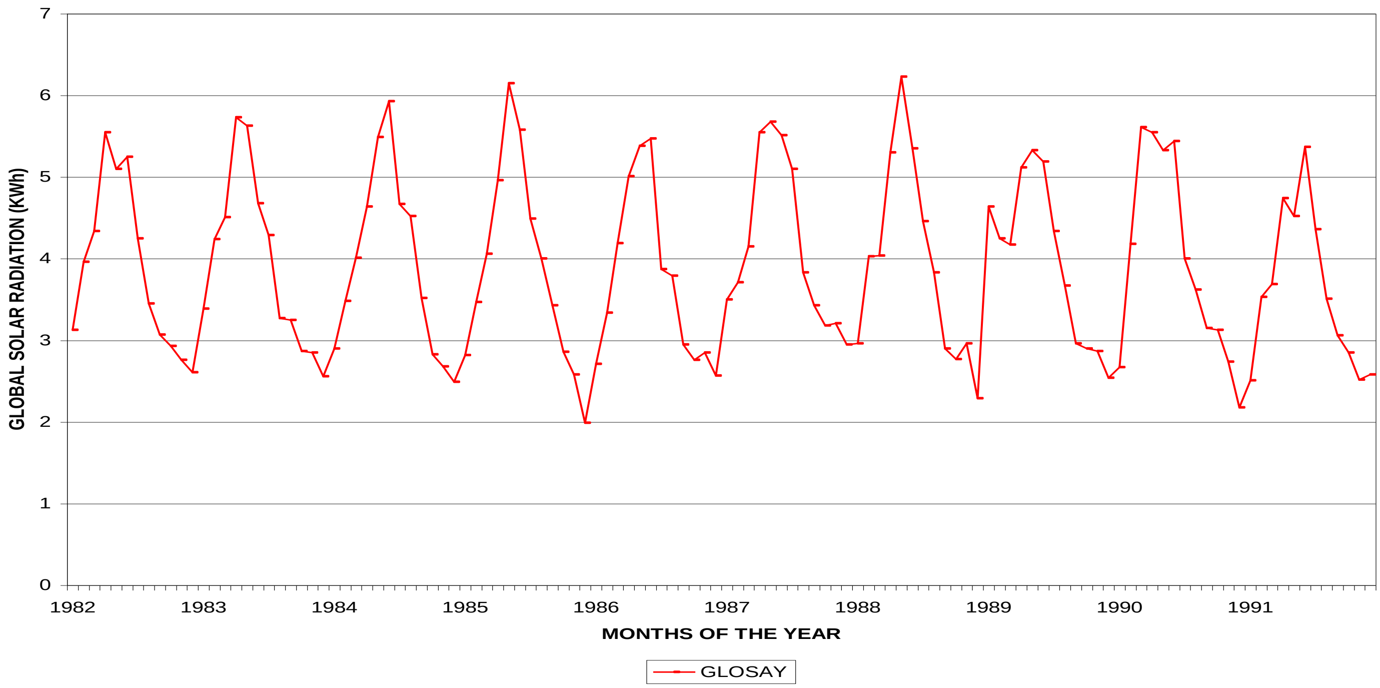

Figure 2. Global solar radiation for the second decade between 1982 to 1991.

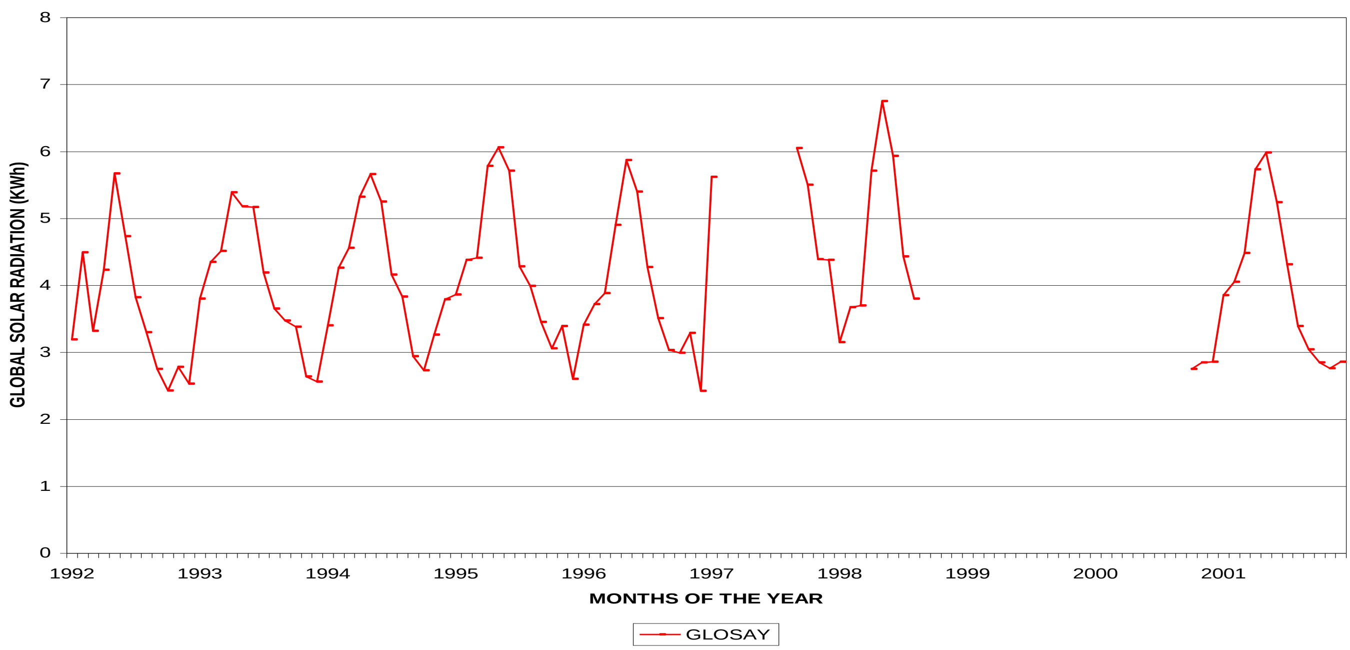

Figure 3. Global solar radiation for the third decade between 1992 to 2001.

revealed that the power need of Nigeria, most especially those within the South-eastern region, could be addressed if the potentials of this renewable energy is adequately harnessed. However, comparing the results from the Sayigh universal formula with those obtained using Angstrom and Hargreaves estimation methods yet over the region as shown in Figure 5; it could be seen that the trend line was similar hence showing an

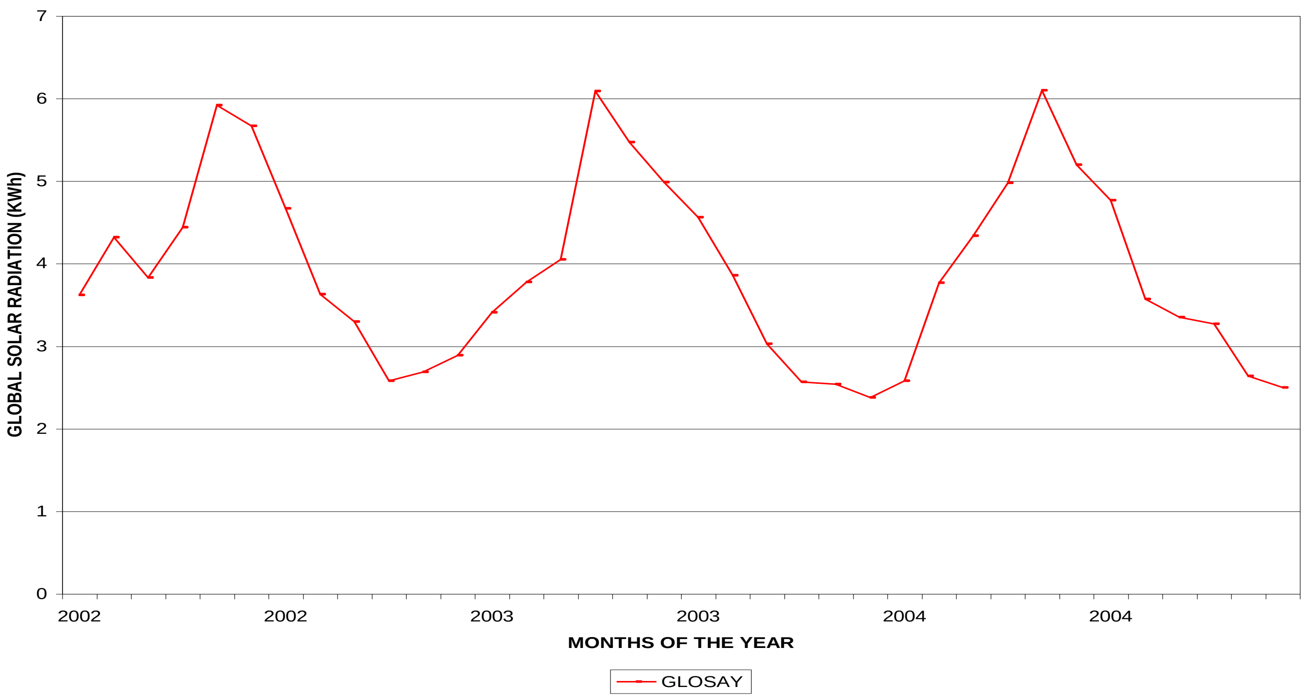

Figure 4. Global solar radiation for the last three years in the fourth decade between 2002 to 2004.

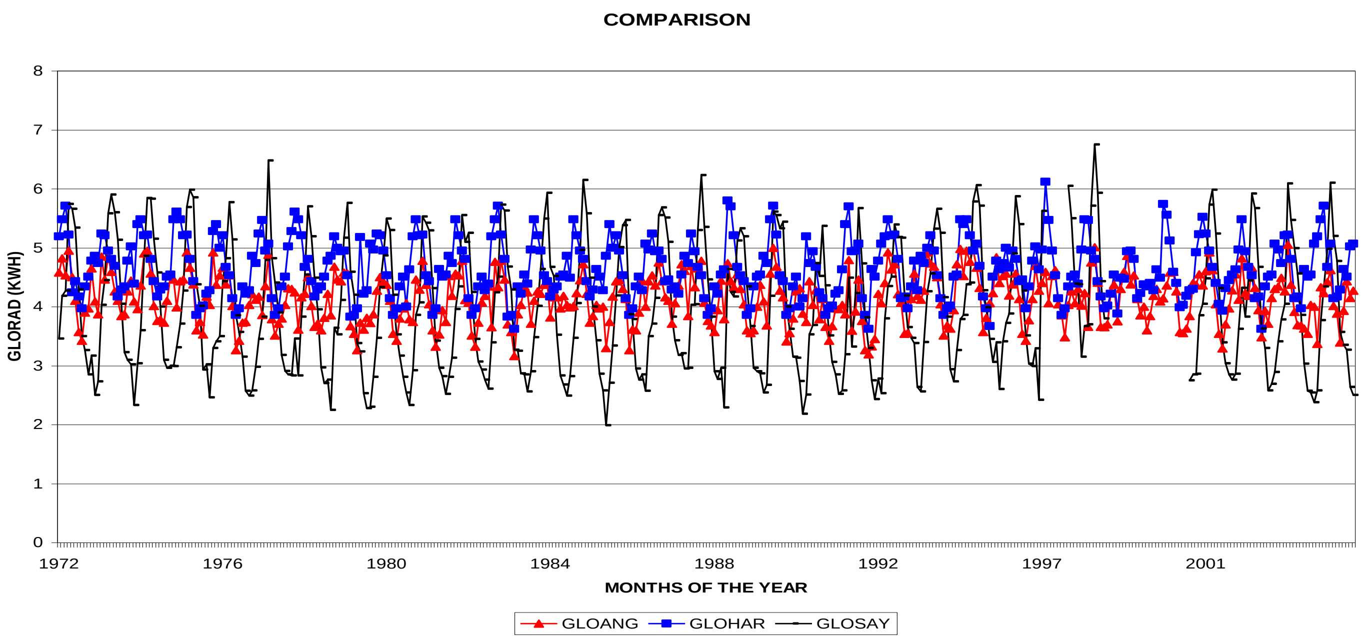

Figure 5. Comparison of levels of Global Solar Radiation at Umudike with the three estimation methods from 1972-2004.

agreement within each estimation method.

Conclusion

From the analyses, it is seen that the levels of global solar radiation recorded over the region were high having least values over the harmattan months as also reported in Chineke et al. (2007). These values are adequate in citing Photovoltaic systems (PV) as there is enough energy to power them all year round (Chiemeka and

Chineke, 2009). Designing and constructing solar cookers, incubators, ovens and preserving equipments that would be affordable but efficient for those living in the rural areas within the study area, becomes necessary as majority of the people living in these area are poor. This will in turn, enhance their living standard (Chineke and Igwiro, 2008), which is one of the objectives of the Millennium Developmental Goals (MDG) of the government.

Photovoltaic systems are now the lowest cost option for satisfying many of the electrical energy needs of areas not served by distributed electricity, particularly in developing countries, located in the tropics, where the amount of sunshine is generally high and rural household electricity consumption is comparatively low. Efforts should therefore be made to improve the number of meteorological stations available so that observations may be obtained from these stations to cover a wider scope.

REFERENCES

Akinbami JFK (2001). Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospects and Policy Framework. Mitigation and Adaptation Strategies for Global Change. 6:155-188. Kluwer Academic Publishers. Netherlands.

Akpabio LE, Etuk SE (2003). Relationship Between Global Solar Radiation And Sunshine Duration For Onne, Nigeria. Turk J. Physics, 27:161-167.

Akpabio LE, Udo SO, Etuk SE (2005). Modeling Global Solar Radiation For A Tropical Location: Onne, Nigeria. Turk J. Physics, 29:63-68.

Angstrom A (1924). Solar and terrestrial radiation. Q. J. R. Meteorol. Soc. 50:121-125.

Angstrom A (1929). Recording Solar Radiation. Medd. Statues meterol. Hyd. Anstalt. 3:4-10.

Black JR, Bonython CW, Precott J (1954). Solar Radiation And The Duration Of Sunshine. Quart J. Roy. METEOR. 80:231-235.

Babatunde EB, Aro TO (1995). Relationship Between “Clearness Index” And “Cloudiness Index” At A Tropical Station (Ilorin, Nigeria), Renewable Energy, 6(7):801-805.

Chiemeka IU, Chineke TC (2009). Evaluating the global solar energy potential at Uturu, Nigeria. Int. J. Phys. Sci. 4(3):115-119. Available Online at http://www.academic journals.org/IJPS.

Chineke TC (2002). A Robust Method Of Evaluating The Solar Energy Potential Of A Data Sparse Site, The Physical Scientist, 1:59-69.

Chineke TC (2008). Equations for estimating global solar radiation in data sparse regions. Renewable Energy 33(4):827-831.

Chineke TC, Aina JI, Jagtap SS (1999). Solar Radiation Database for Nigeria, Discovery & Innovation, 11(3/4):207-210.

Chineke TC, Igwiro EC (2008). Urban and rural electrification: enhancing the energy sector in Nigeria using photovoltaic technology, UNESCO/ANSTI Afr. J. Sci. Technol. 9(1):102-108.

Chineke TC,Jagtap SS (1995). A Comparison of Three Empirical Models For Estimating Solar Radiation In Nigeria. Afr. J. Sci. Technol. Series A, 11:45-48.

Chineke TC, Okoro UK, Igwiro CE (2007). The Imperatives Of Solar Photovoltaic As Viable Options for Rural Electrification in Nigeria. Int. J. Nat. Appl. Sci. 3(2):193-199.

El-Sahaam MA, Sayigh AA M (1979). Estimation of Diffuse Solar Radiation In The Arabian Pem Proc. Symp. On Radiation in The Atmosphere. Ed. J. A. Book Sc. Press, pp. 607-610.

Hargreaves GH, Samani ZA (1982). Estimating Potential Evapotranspiration. J. Irrig. Drainage Engr. 108(IR3):225-230.

Igbal M (1983). An introduction to solar radiation. Academic Press, New York.

Oduro- Afriyie K (1997). Performance of Sayigh’s universal formula for the estimation of global solar radiation in Ghana. Renewable Energy, 10(1):91-106.

Okoro UK, Chineke TC, Nwofor Ok, Ibe A (2008). Evapotranspiration Levels At Owerri In The Niger Delta Nigeria. Int. J. Nat. Appl. Sci. 4(2):168-173.

Sayigh AAM (1977). Estimation of total radiation intensity a universal formula in 4th course of solar energy convention, Vol. II Mancin and Quercia I. F. (Eds), ICTP, Trieste, Italy.

Taimur B, Amine M, David C, Joseph N (2007). IMF Working Paper No. 07/71, March 2007.